similitude to an oblique section of the shell of some Mollusca, such as *Pinna*.

The author then proceeds to describe in detail and with particularity the form and progressive growth of the several elements of the tooth as they are met with in examining the growing extremity and proceeding from it towards the mature structure, as long as the elements are susceptible of isolation and individual examination. The anatomy of the soldering particles, and their relation to the production of the cavitary structure of the tooth, is specially dwelt upon. The soldering particles are supposed to be isolated at first, but as they enlarge they become connected by a thin film from their upper and under faces. This occurs before the final consolidation of the tissue, and before the soldering particles are indissolubly connected with, and themselves indissolubly connect, the contiguous elements of the tooth. At this stage these particles are still susceptible of isolation, and they may be separated *en masse*, being held in relative position by the films that connect them. The soldering particles and the connecting films thus constitute a tubular system, which has an independent existence before the final consolidation of the tissue, and this tubular system is introduced between, and interpolated among the previously existing elementary parts of the tooth.

The author concludes by expressing a coincidence of opinion with Dr. Carpenter, that the minute structure of the tooth is essentially of the same nature as that of the shell of the Echinidæ generally.

April 11, 1861.

Major-General SABINE, R.A., Treasurer and Vice-President, in the Chair.

The following communications were read:—

I. "On the Motion of a Plate of Metal on an Inclined Plane, when dilated and contracted; and on the Descent of Glaciers." By the Rev. HENRY MOSELEY, M.A., Canon of Bristol, F.R.S., Inst. Sc. Paris Corresp. Received March 14, 1861.

(Abstract.)

The case in which the upper edge of such a plate (supposed rec-

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tangular) is fixed is first discussed; and then that in which the lower edge is fixed. Each of these cases is considered subject to the condition of friction; first, when the plate is dilated, and secondly, when it is contracted. Two other principal conditions arise in the discussion; one being that in which a part only, and the other that in which the whole of the plate dilates and contracts.

In the former the dilatation or contraction is represented by

$$\frac{\mathrm{E}\,\lambda^2\,t^2\cos\phi}{2\mu(1\pm\lambda t)\sin(\phi\pm\iota)},$$

or by

$$\frac{\mathrm{E}\,\lambda^2\,t^2\cos\phi}{2\mu(1\mp\lambda t)\sin(\phi\mp\iota},$$

according as the plate is fixed at the top or the bottom.

In the latter it is represented under the same conditions by

$$a\left\{\lambda t-\frac{\mu\sin(\phi\pm\iota)}{2\mathrm{E}\cos\phi}a\right\}$$

or by

$$a\left\{\lambda t-\frac{\mu\sin(\phi\mp\iota)}{2\mathrm{E}\cos\phi}a\right\}.$$

In which formulæ—

a represents the length of the plate.

μ its weight in lbs. per foot of its length.

ι the inclination of the plane.

ϕ the limiting angle of resistance (the angle of friction) between the surface of the plane and of the plate.

E the modulus of elasticity of the plate.

λ the dilatation or contraction per foot of the length for each variation of 1° of Fahrenheit.

$\pm t^\circ$ the rise or fall of the temperature in degrees of Fahrenheit, by which the dilatation or contraction of the plate is supposed to be caused.

In the case in which no part of the plate is fixed a horizontal line may be taken in it above which it *dilates* upwards, and below it downwards. The position of this line is determined by the consideration that, if the plate be imagined to be cut through along that line, the thrust necessary to push the part above upwards must be equal to that necessary to push the part below downwards.

In like manner a horizontal line may be found above which the plate *contracts* downwards and below it, upwards.

The former neutral line is nearer the top than the bottom, the other nearer the bottom than the top. The one is at the same distance from the top as the other is from the bottom. This distance is represented by the formula

$$\tfrac{1}{2}a\frac{\sin(\phi-\iota)}{\sin\phi\cos\iota}.$$

When the plate is dilated, it is the longer portion which dilates *downwards*; and when it is contracted, it is the shorter portion which contracts *upwards*. The lower end of the plate descends therefore by a given increase of temperature more than it ascends by an equal fall; and on the whole the plate descends.

If we suppose the temperature first to be increased by t_1^0, and then diminished by t_2^0; then—

1st. In the case in which a portion only of the plate dilates, the descent is represented by

$$\frac{E\lambda^2\cos\phi}{2\mu}\left\{\frac{t_1^{\,2}}{(1+\lambda t_1)\sin(\phi-\iota)}-\frac{t_2^{\,2}}{(1-\lambda t_2)\sin(\phi+\iota)}\right\}.$$

2ndly. In the case in which the whole plate dilates and the whole contracts, the descent is

$$\tfrac{1}{2}a\left\{(t_1-t_2)\lambda+(t_1+t_2)\frac{\tan\iota}{\tan\phi}-\frac{\mu a\sin(\phi+\iota)\sin(\phi-\iota)\tan\iota}{E\sin^2\phi\cos\iota}\right\}.$$

The first case passes into the second.

If E be very great as compared with μa, the second term in the above formula may be neglected. It then corresponds with the formula given by the author in a former communication to the Society.

To verify the fact of the descent of a plate of metal under the conditions supposed, a deal board 9 feet long and 5 inches broad, was fixed at an inclination of 18½° against the wall of a house having a southern aspect, and a sheet of lead was placed upon it one-eighth of an inch thick and weighing 28 lbs., and having its edges turned over the edges of the board so as not to bind upon it. Near the lower extremity a vernier was constructed, by which the position of the lead on the board could be determined to the 100th of an inch. Its position was observed daily between 7 and 8 in the morning and 6 and 7 in the evening, from the 16th of February to the 28th of June, 1858.

A Table is given showing the descent for every day of that period, from 7 A.M. to 6 P.M. and from 6 P.M. to 7 A.M.

In the months when there was no sunlight from 6 P.M. to 7 A.M., there was no descent in that interval. The descents from 7 A.M. to 6 P.M. were very different on different days. Sometimes they amounted to a quarter of an inch in the day, and sometimes were not appreciable. The greatest descents were on sunny days, and especially when with a warm sun there was a cold wind. The least were on days of continual rain. The average daily descents were, in inches,—

February.	March.	April.	May.	June.
·10000	·13806	·16133	·21500	·21888

These descents were not due to the extreme temperatures of the periods in which they took place, but to the aggregate of the variations up and down during each interval. The difference of the highest and lowest temperatures in any interval may have been small, and yet the changes of temperature up and down may have been many, and their aggregate great. It is upon this aggregate that the descent depends.

The dilatation of ice was measured in the years 1845, 1846, at the Observatory of Pultowa, by Schumacher, Pohr, and Moritz; and the particulars of their experiments were communicated to the Academy of St. Petersburgh, by W. Struve, in 1848, and published in its Memoirs (Sciences Mathém. et Phys., sér. 6. t. iv.). By exposing water to the action of the frost in a mould, Schumacher obtained a block of ice, which, after reducing it with the plane, measured 6 ft. 3 ins. in length and 6 ins. by 6½ inches in section; and he caused three thermometers to be frozen into it with their stems projecting above its surface. This block of ice he carried out from a room, where it had been preserved at a uniform temperature of −2° R. during the day, into the open air at night, and slung it in a horizontal position from a beam supported by tressles. As its temperature fell he measured the distance between two steel points frozen into it near its two ends, by a measuring rod of dry wood (well-clothed), the distances on which were referred to a standard measure on the wall of a room of the Observatory which retained nearly a constant temperature of $-2°$ R. His measurements had reference to observed temperatures of the ice varying from $-2°{\cdot}3$ R. to $-22°$ R. After applying the requisite corrections, it resulted from them that the coefficient of expansion of ice is for $1°$ R.

$$\cdot 00006466,$$

which is *nearly* twice as great as the coefficient of dilatation of lead, and *more* than twice as great as that of any other solid.

We do not know the modulus of elasticity of ice, or the pressure under which it disintegrates.

If it were as elastic as slate and did not resist crushing more than hard brick, a block of it placed with its ends between two immoveable obstacles, would crumble when its temperature was raised one degree of Fahrenheit. It is its great dilatability which gives to ice this tendency to disintegrate, when, not being free to dilate, its temperature is raised*, even so slightly as this.

If the block of ice experimented on by Schumacher had been placed upon a plank inclined at the same angle as that used in the experiment with the lead was, and if its under side had been coated with lead-foil so as to give it the same friction on the plank as the lead had, then, under the same variations of temperature as the lead experienced, it could not but have descended as the lead did, but twice as fast, because its dilatability is twice as great.

We may conceive such a block of ice to be made up of thin plates parallel to its upper surface, such as plates of glass would be, if glass were as dilatable as ice and as friable, and if it possessed that property of passing from a disintegrated into a solid state, which in ice is called regelation. If we put the adherence of these plates to one another in the place of friction, and conceive the variations of external temperature (or the effects of solar radiation) to reach them in succession, each one being dilated or contracted independently of the rest, then each would descend by a motion proper to itself, and also by reason of the descents of those subjacent to it. The extremities of the plates would under these circumstances overlap, and the descent of each, proper to itself, would be increased by the overlappings of those beneath it.

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* Agassiz describes a disintegration of the transparent ice of the blue bands of glaciers when laid bare, which appears to be due to its expansion.—Bulletin Un. de Genève, vol. xliv. p. 142.

Each plate would under these circumstances descend faster than the one beneath; and supposing the adherence of the lowest plate to the board to be the same as that of the plates to one another, then, of any number of blocks similarly placed and subject to the like variation of temperatures, the thickest or deepest would descend, at its surface, the fastest; and if there were a block of different depths in different parts, the deepest parts would descend the fastest. The differential motion thus set up would not be appreciable in a block of ice of different thicknesses in different parts if its dimensions were no larger than the block experimented on by Schumacher, but in a glacier it would be appreciable.

To bring Schumacher's block to the proportions of a glacier, it must be converted into a slab twelve feet long, twenty inches wide, and two inches thick. It would then represent on a scale of the 1500th part, a glacier 2500 feet wide, 250 feet deep, and 18,000 feet long, which are something like the dimensions of the Mer de Glace from 2300 feet below Montanvert to the Tacul. If we suppose it to be placed at the same inclination of $18\frac{1}{2}^{\circ}$ at which the lead was, its under surface being coated with lead so as to have the same friction on board as the lead had, then it may be calculated that if it had experienced the same variations of temperature as the lead did, its average daily descent, measured in inches, would have been

February.	March.	April.	May.	June.
·26666	·36816	·43022	·57334	·58368

If, now, we conceive its inclination to change from $18\frac{1}{2}^{\circ}$ to that of the Mer de Glace, which is about 5°, and its dimensions to become actually those of that glacier, then, supposing the glacier to experience the same elevations and depressions of temperature as the lead did, its average daily descents in inches would be

February.	March.	April.	May.	June.
104·56	144·06	168·74	224·87	228·92

which rates of motion are probably twelve times greater than the actual rates of motion of the glacier; showing that variations of the temperature of the glacier twelve times less than those of the lead, would be sufficient to produce its actual descent; or that it would descend as it actually does, if the resistances opposed to its descent were twelve times greater than the resistances opposed to the descent of the lead—If its descent were resisted by a friction, for instance, having twelve times the coefficient of that of the lead on the board, or such as would cause it to rest without slipping on an incline having twelve times the tangent of the inclination of the board; or if the variations of temperature were less and the resistance greater in any proportion which would retard the descent twelve times as much. So that we may suppose in the case of the glacier a far greater resistance in proportion than that sustained by the lead upon the board, and variations of temperature far less, without passing the limits within which a probability is created by the experiment that the descent of the glacier is due to the same cause as that of the lead.

In the act of descending on the board, the slab of ice of which we have spoken could not but be thrown into a state of extension in some parts and of compression in another. The conditions of the descent being in other respects given, the amount of this extension or compression might be at any point determined. If at any point the extension exceeded the tenacity of the ice, the slab would there separate across its length; and if at any point the compression exceeded the resistance to crushing, it would there crush.

Supposing it to be thinner at the sides than in the middle, the surface-motion of the middle would be faster than that of the sides, and from this differential motion would result cracks oblique to the axis of the slab, the explanation of which, as they exist in glaciers, is one of the most successful attempts yet made at the solution of the mechanical problem of glacier-motion. These conditions of the descent of the slab, when referred to a glacier, explain the formation of transverse and lateral crevasses, and the fact of a glacier crushing itself through a gorge.

The Mer de Glace moves faster by day than by night*. Its mean daily motion is twice as great during the six summer as during the six winter months †. It moves fastest in the hottest months, and in those months varies its motion the most, because in them the variations of temperature are the greatest. It moves most slowly in the coldest months, and in those varies its motion the least, because in those months the variations of temperature are the least. These differences are more remarkable at lower stations on a glacier than at higher, "because the lower are exposed to more violent alternations of heat and cold than the higher : this (says Forbes) we shall find to be general."

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* Forbes, 'Occasional Papers,' p. 12.

† Ibid. p. 129. Tyndall, 'Glaciers of the Alps,' p. 294.

It moves fastest on the hottest days. "This I apprehend (says Forbes) to be clearly made out from my experiments, that thawing weather and a wet state of the ice conduce to its advancement, and that cold, whether sudden or prolonged, checks its progress *." "The striking variations in September, especially at the lower stations, which were frequently observed, prove the connexion of temperature with velocity to a demonstration†."

It is, however, impossible to do justice to the positive character of the evidence on which this conclusion has been founded by Professor Forbes without reference to those diagrams, by means of which he has compared the mean rates of the daily motions of glaciers and the corresponding mean temperatures. This comparison is founded on observations made by himself and Aug. Balmat, as to the motion of the "Mer de Glace," at fourteen different stations in three different years, and on observations on the mean temperature of the atmosphere made at the same times at the Great St. Bernard and at Geneva. It results from it that no change in the mean temperature of the atmosphere is unaccompanied by a corresponding change in the mean motion of the glacier.

The glacier moves with different velocities at different depths, the surface-motion being faster (probably two or three times) than that of the deepest part. The motions at different depths cannot but be related to one another: so that as the influence of variations of temperature is felt on the *surface*, it cannot but be felt throughout the glacier.

If every change of solar heat is associated with a corresponding change of glacier-motion, it seems to follow that the two are either dependent upon some common cause, or that the one set of changes is caused by the other ; and the former of these conclusions being inadmissible, we are forced on the latter. It is not necessary to show how it is that changes of external temperature penetrate glaciers. Of the power of the sun upon them there are, however, evidences in the ablation of surface constantly going on and in the preservation of the ice which is covered by the stones of a moraine, which sometimes forms an icy ridge from 50 to 80 feet high, and some hundred feet in width.

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* Forbes, 'Travels in the Alps,' p. 148.

† Ibid.

"The sun's rays," says Tyndall*, "striking upon the unprotected surface of the glacier, *enter the ice to a considerable depth*; and the consequence is that the ice near the surface of the glacier is always disintegrated, being cut up into minute fissures and cavities filled with water and air, which, for reasons already assigned, cause the glacier when it is clean to appear white and opaque. The ice under the moraines, on the contrary, is usually dark and transparent. I have sometimes seen it as black as pitch, the blackness being a proof of its great transparency, which prevents the reflexion of light from its interior. The ice under the moraines cannot be assailed in its depths by the solar heat, because this heat becomes obscure before it reaches the ice, and as such it lacks the power of penetrating the substance. It is also communicated in great part by way of contact instead of by radiation. A thin film at the surface of the moraine ice engages all the heat that acts upon it, its deeper portions remaining transparent and intact."

It matters not to the argument how little below freezing the temperature of a glacier may be. So long as the ice *exists in a solid state* and is capable of being penetrated by the solar heat, it cannot but dilate and contract. Its central portions, lying folded in ice 100 feet thick above and below, may well, however, be conceived to retain some of the cold of the region from which they have descended. The observations of Agassiz on the temperature of the Aar Glacier are not to be relied upon, because the access of damp external air to the borings in which they were made, and of water percolating the disintegrated ice of the surface, was not effectually stopped. The included thermometers could not but under these circumstances show zero, although the temperature of the surrounding ice was below it. For the water freezing on the walls of the boring, the latent heat thereby given out, would raise the temperature of the air about the bulb to the freezing-point, and this water being continually renewed, the quicksilver would always be kept at that point.

That glacier-ice possesses no such properties of viscidity or compressibility as would cause it to descend by its weight along such slopes as those on which some glaciers descend may be shown thus. Let the Mer de Glace be conceived to be cut up by vertical sections at right angles to one another, into blocks, whose bases are large enough to prevent them toppling over; and let these blocks be imagined to be separated from one another. Then (supposing it not to slip) each block would stand in its place without the support of the neighbouring blocks; for its vertical sides would be walls of ice needing no external support, like the ice-wall of the Glacier du Géant, 141 feet high near the Tacul, described by Tyndall*; or that of the Mer de Glace near the Augle, pictured by Forbes†. Needing no external support when thus placed asunder, they could need none when brought again together; nor could they, by the fact of their being so brought together, be made to exert any mutual pressure, or have any more or other tendency to move than each block had separately. If this reasoning be true, there is no physical property of ice, whether it be called viscosity or plasticity, which would cause it to descend by its weight alone on any surface along which it would not slide. It is plastic no doubt—Tyndall has proved that by the Hydraulic Press,—but not as to any pressure created in a glacier by the weight of the glacier. If it were, or if it were semifluid, then under those enormous pressures which it is supposed to sustain, it would bulge out at the ice-wall of the Tacul, and mould itself to the sides of its channel; for it is the character of a compressible substance, not less than of a semifluid, to yield not only in the direction in which pressure is applied to it, but in every other.

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* Glaciers of the Alps, p. 294.

Nor if it were sufficiently a fluid to flow by its weight alone, however slowly, down slopes of 3° or 5°, could it descend otherwise than as a torrent down slopes, such as that of the Silberberg Glacier, of 40°, on which its descent is nevertheless several times slower. The phenomena of these secondary glaciers offer themselves as a test of rival theories of glacier-motion. They lie on slopes so steep that it is scarcely possible to conceive the ice, if solid, to be loosened from the face of the rock, and not to descend in fragments; or if viscous, not to become a torrent.

II. "Preliminary Note on the production of Vibrations and Musical Sounds by Electrolysis." By George Gore, Esq. Communicated by Professor Tyndall. Received April 4, 1861.

If a large quantity of electricity is made to pass through a suitable good conducting electrolyte into a small surface of pure mercury,

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* Glaciers of the Alps, p. 289.

† Travels in the Alps, p. 76.